Coagulation-Clarification of Coloured Water Using Natural Coagulant (*Moringa oleifera*)

by

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the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

(Professor Malay Chaudhuri)

UNIVERSITI TEKNOLOGI PETRONAS

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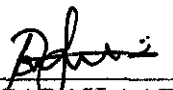
CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



PUTRI SARAH AAINAA BT KHAIRULDIN

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ABSTRACT

This paper presents the progress achieved in the study of coagulation-clarification of coloured water using a natural coagulant (*Moringa oleifera*). The main objective of this project was to evaluate the efficiency of *Moringa oleifera* seed extract as primary coagulant and coagulant aid in treating coloured water in Malaysia. A number of jar tests with low turbidity (ca. 50 NTU) and medium-level true colour condition (ca. 50 CU) with corresponding apparent colours were carried out within the project timeline. The model turbid water (ca. 50 NTU and 50 CU) underwent three different tests; by using aluminium sulphate as primary coagulant, *Moringa oleifera* seed extract as primary coagulant and *Moringa oleifera* seed extract coagulant aid. *Moringa oleifera* seed extract reduced turbidity and colour of the river water, but it was less effective compared to aluminium sulphate. Alum (25 mg/l) produced excellent clarification (filtrate turbidity: 1.72 NTU; filtrate colour: 3.0 CU), where as *Moringa oleifera* seed extract (500 mg/l) produced acceptable clarification (filtrate turbidity: 4.24 NTU; filtrate colour: 15.0 CU). Combination of aluminium sulphate (15 mg/l) and *Moringa oleifera* seed extract (80 mg/l) produced comparable and consistent clarification (filtrate turbidity: 3.54 NTU; filtrate colour: 13.0 CU).

Key words – water treatment, coagulation-flocculation, aluminium sulphate, *Moringa oleifera*, natural polyelectrolyte, colour removal, jar test

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Recently, water supply in Malaysia has changed from one of relative abundance to one of scarcity. Population growth and urbanization, industrialization and the expansion of irrigated agriculture are imposing rapidly increasing demands and pressure on water resources. Moreover, these also contribute to the rising of water pollution which causes the process of water treatment to become more complicated (Oh Yong Pin, 2006).

Although there are quite number of water treatment plants in this country, most of them are practicing the conventional method to treat water, whereby using large quantity of chemicals (i.e. aluminium sulphate, lime, polymers and chlorine). With that, alternative ways need to be developed in order to reduce the cost and other disadvantages caused by the chemicals. Local available materials (natural coagulant) need to be introduced and tested as alternatives to the chemicals. The present study was undertaken to assess the effectiveness of *Moringa oleifera* seed extract, a natural polyelectrolyte, as coagulant and coagulant aid in clarifying turbid coloured water.

1.2 Problem Statement

Aluminium sulphate is a well known industrial chemical that has been significantly used in water treatment due to its effectiveness. However, recent studies have pointed out several serious drawbacks of using alum associated with Al in drinking water, e.g. Alzheimer's disease (Crapper et. al., 1973; Kaggwa et. al., 2001). Unlike alum, *Moringa oleifera* seed is environmental friendly, and does not significantly affect the pH and conductivity of the water after treatment. Besides, economic factor also had been put into consideration as many developing countries can hardly afford the high costs of imported chemicals for water and wastewater

treatment in a long term usage. (Ndabigengesere *et. al.*, 1995) In this context, natural coagulants present a viable alternative.

1.3 Significance of the Project

The importance of this study would be to ascertain the efficiency of *Moringa oleifera* seed extract as coagulant and coagulant aid in water treatment. By using the locally available material, the water treatment cost is expected to be lower, thus be a cost affective alternative to the existing chemical coagulants. The comparison between *Moringa oleifera* seed and aluminium sulphate (alum) as primary coagulant is essential in determining the effectiveness of the *Moringa oleifera* seed in treating water from river system or other aquatic systems with different turbidity and colour concentration.

Other than that, application of *Moringa oleifera* seed as coagulant aid with alum as primary coagulant will definitely give an idea in reducing the amount of alum, thus reduce the cost of purchasing alum. In addition, *Moringa oleifera* seed extract does not give any significant impact to pH of water. They are also not toxic to humans or animals (Grabow *et al.*, 1985; Berger *et al.*, 1984). Therefore, exploring an alternative by using natural coagulant might help in developing an economical, environmental friendly and low health risk method in water treatment.

1.4 Objective

- To evaluate the efficiency of *Moringa oleifera* seed extract as primary coagulant in treating coloured water from river system.
- To evaluate the efficiency of aluminium sulphate as primary coagulant in treating coloured water from river system.
- To evaluate the efficiency of aluminium sulphate as primary coagulant and *Moringa oleifera* seed extract as coagulant aid in treating coloured water from river system.

- To compare the effectiveness of aluminium sulphate and *Moringa oleifera* seed extract as coagulant in river water treatment.
- To determine the optimum dosage for both *Moringa oleifera* seed and aluminium sulphate.

1.5 Scope of the Study

The scope of the study covers mainly laboratory work, which is batch clarification test – jar test. By running the test on different turbidity and colour concentration of the river water with sedimentation and filtration, the optimum dosage of the *Moringa oleifera* seed (as primary coagulant or coagulant aid) will be obtained. Besides that, the optimum dosage of the chemical coagulant, aluminium sulphate needs to found out precisely. The results will be used for comparison with the natural coagulant. The pH will be measured before and after the test to determine the effect of pH on coagulation. The parameters in the study are pH, true colour, apparent colour, turbidity and optimum dosage. A conclusion to the study will be made based on the results.

CHAPTER 2

LITERATURE REVIEW

2.1 Water Clarification

Water clarification is the process of removing suspended solids from water. In this sub-chapter, factors governing the destabilization, coagulation and removal of suspended solids from water are reviewed.

2.1.1 Subsidence

While a degree of clarification can be accomplished by subsidence (settling), most industrial processes require better quality water than can be obtained from subsidence only. Most of the suspended matter in water would settle, given enough time, but in most cases the amount of time required would not be practical. The time required for settling is dependent on many factors, including; weight of the particle, shape of the particle, size of the particle, and lastly viscosity and/or frictional resistance of the water, which is a function of temperature. The settling rates of various size particles at 50 °F (10 °C) is illustrated in ***Table 2.1***.

Table 2.1: Settling rates by particle size

Diameter of Particle (in mm)	Types of Particles (by order of Particle (mm) magnitude)	Time Required (to Settle One Foot)
10.0	Gravel	0.3 seconds
1.0	Coarse sand	3.0 seconds
0.1	Fine sand	38.0 seconds
0.01	Silt	33.0 minutes
0.001	Bacteria	35.0 hours
0.0001	Clay particles	230.0 days

(Source: Gulf Coast Chemical Commerical, Inc., 1998).

Settling velocities may be calculated from Stokes' Law:

$$V = \frac{2662(S_1 - S_2)D^2}{z} \qquad (2\text{-}1)$$

where;

V = Velocity of fall (ft/sec)

D = Diameter of particle (in)

S_1= Density of particle (lb/ft^3)

S_2= Density of fluid (lb/ft^3)

z = Viscosity (centipoises)

In this equation it is assumed that the particles are spherical, failing under viscous resistance, and that they have no electrostatic charges. This is, of course, never true under actual conditions. Most suspended solids smaller than 0.1 mm found in surface waters carry negative electrostatic charges. This charge causes the particles to repel each other, increasing their stability and thus increasing their tendency to remain suspended. Chemicals are often added to water to neutralize particle charge and enhance particle settling. Chemicals used to promote suspended particle subsidence in the clarification process are commonly called coagulants; the particle charge neutralization process is called coagulation.

2.1.2 Coagulation

Coagulation, the first step in complete clarification, is the neutralization of the electrostatic charges on colloidal particles. Because most of the smaller suspended solids in surface waters carry a negative electrostatic charge, the natural repulsion of these similar charges causes the particles to remain dispersed almost indefinitely. To allow these small suspended solids to agglomerate, the negative electrostatic charges must be neutralized (***Figure 2.1***). This is accomplished by using inorganic coagulants (water soluble inorganic compounds), organic cationic polymers or polyelectrolytes.

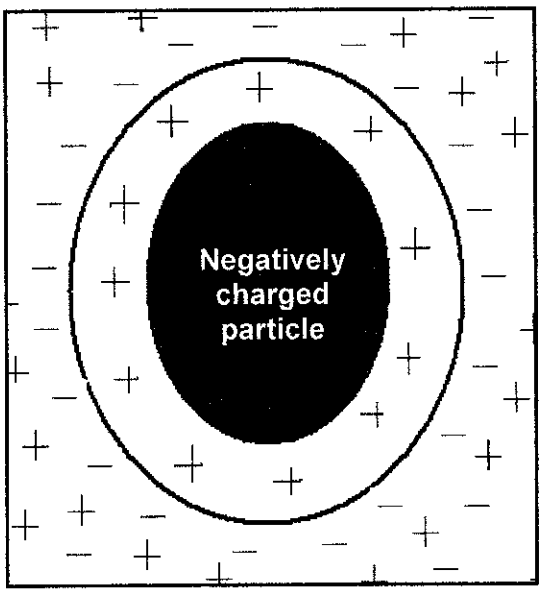


Figure 2.1: A negatively charged colloid with a possible configuration of ions around it.

The most common inorganic coagulants are aluminum sulphate - $Al_2(SO_4)_3$, ferric sulfate - $Fe_2(SO_4)_3$, ferric chloride - $FeCl_3$ and sodium aluminate - $Na_2AI_2O_4$. Inorganic salts of metals work by two mechanisms in water clarification. One of them is the electrostatic potential which created by the "halo" of the counter ions surrounding each colloid and reacts to repel the particles. The second force, an attraction force called the van der Waals Force, supports contact. This force is inversely proportional to the sixth power of the distance between particles and also decays exponentially with distance. The sum of the two forces, the net force, as they relate to one colloid in close proximity to another, is repulsive force, called the energy barrier, at some distance between the colloids (***Figure 2.2*** in Appendices). For the agglomeration to occur, the energy barrier needs to be overcome.

The positive charge of the metals serves to neutralize the negative charges on the turbidity particles. The metal salts also form insoluble metal hydroxides which are gelatinous and tend to agglomerate the neutralized particles. The effectiveness of inorganic coagulants is dependent upon water chemistry (pH and alkalinity), and their addition usually alters that chemistry.

2.1.2.1 Alkalinity Relationships

Aluminum salts are most effective as coagulants in a 5.5-8.0 pH range. Because they react with the alkalinity in the water, it may be necessary to add additional alkalinity in the form of lime or soda ash. Iron salts, on the other hand, are most effective as coagulants at higher pH ranges (8 to 10). Iron salts also depress alkalinity and pH levels; therefore, additional alkalinity must be added. Sodium aluminate increases the alkalinity of water, so care must be taken not to exceed pH and alkalinity guidelines. As is evident from the reactions discussed above, a working knowledge of the alkalinity relationships of water is mandatory.

It is important to note that the use of metal salts for coagulation may increase the quantity of dissolved solids. One must consider the downstream impact of these dissolved solids. In addition, the impact of carryover of suspended Al^{+++} and Fe^{+++} compounds and their related effect on downstream processes must be considered. For example, if the alum demand of water is 50 ppm, the sulfate increase in the effluent water would be 50 ppm x 0.45, or 22.5 ppm. If an equivalent amount of lime had to be added, the dissolved solids content of the water would be further increased by

$$50\ ppm \times (0.45/1.26) = 17.9\ ppm \qquad (2\text{-}2)$$

It must also be pointed out that using inorganic coagulants produces a voluminous, low-solids sludge that dewaters and dries very slowly.

2.1.3 Flocculation

Flocculation exhibits the second step of the coagulation process. Once the negative charges of the suspended solids are neutralized, flocculation begins. Charge reduction increases the occurrence of particle-particle collisions, promoting particle agglomeration. Portions of the polymer molecules not absorbed protrude for some distance into the solution and are available to react with adjacent particles, promoting

flocculation. Bridging of neutralized particles can also occur when two or more turbidity particles with a polymer chain attached come together. It is important to remember that during this step, when particles are colliding and forming larger aggregates, mixing energy should be great enough to cause particle collisions but not so great as to break up these aggregates as they are formed.

In some cases flocculation aids are employed to promote faster and better flocculation. These flocculation aids are normally high molecular weight anionic polymers. Flocculation aids are normally necessary for primary coagulants and water sources that form very small particles upon coagulation. A good example of this is water that is low in turbidity but high in color (colloidal suspension).

2.1.4 Colour Removal

By far the most difficult impurity to remove from most surface waters is colour (from dissolved or colloidal suspensions of decayed vegetation) and other colloidal suspensions. Colour in surface water normally is a result of its contact with decayed vegetation and is composed of tannins and lignins, the components that hold together the cellulose cells in vegetation. In addition to their undesirable appearance in drinking water, these organics can cause serious problems in downstream water purification processes. For example; some of these organics have chelated trace metals, such as iron and manganese within their structure, which can cause serious deposition problems in a cooling system. There are many ways of optimizing colour removal in a clarifier:

1. Pre-chlorination (before the clarifier) significantly improves the removal of organics as well as reducing the coagulant demand.
2. The proper selection of polymers for coagulation has a significant impact on organic removal.
3. Colour removal is affected by pH. Generally, organics are less soluble at low pH.

Should organic removal prove to be a problem, a relatively simple test procedure is available to determine removal efficiency.

2.2 Aluminium Sulphate

Aluminium sulphate, written as $Al_2(SO_4)_3$ or $Al_2O_{12}S_3$, is a widely used industrial chemical. It occurs naturally as the mineral alunogenite. Aluminium sulphate is rarely, if ever, encountered as the anhydrous salt. It forms a number of different hydrates, of which the hexadecahydrate $Al_2(SO_4)_3 \cdot 16H_2O$ and octadecahydrate $Al_2(SO_4)_3 \cdot 18H_2O$ are the most common. Aluminium sulphate may be made by dissolving aluminium hydroxide, $Al(OH)_3$, in sulfuric acid, H_2SO_4:

$$2Al(OH)_3 + 3H_2SO_4 + 3H_2O \rightarrow Al_2(SO_4)_3 \cdot 6H_2O \qquad (2\text{-}3)$$

It is used in water purification and as a mordant in dyeing and printing textiles. In water purification, it causes impurities to coagulate which are removed as the particulate settles to the bottom of the container or more easily filtered. This process is called coagulation or flocculation. When dissolved in a large amount of neutral or slightly-alkaline water, aluminium sulphate produces a gelatinous precipitate of aluminium hydroxide, $Al(OH)_3$. In dyeing and printing cloth, the gelatinous precipitate helps the dye adhere to the clothing fibers by rendering the pigment insoluble.

Alum is sometimes used to reduce the pH of garden soil, as it hydrolyzes to form the aluminium hydroxide precipitate and a dilute sulfuric acid solution. It is also the active ingredient of some antiperspirants; however, beginning in 2005 the US Food and Drug Administration no longer recognized it as a wetness reducer.

Besides that, aluminium sulphate can usually found in baking powder. In construction industry it is used as waterproofing agent and accelerator in concrete. Another use is a foaming agent in fire fighting foam. It is also used in styptic pencils, and pain relief from stings and bites; it is the active ingredient in popular pain relief products such as Stingose.

2.3 Natural Polyelectrolytes

Polyelectrolytes can be derived from natural source or synthesized by chemical manufacturers. Both types consist of repeating units of small molecular weight, chemically combined to form a larger molecule of colloidal size and each of that carrying electrical charges or ionizable groups. Classification of the polyelectrolyte is made by the type of charge they carry. The polymers that possess negative charges are called anionic while those possessing positive charges are called cationic. For those carrying both charges is called ampholytic.

Synthetic polyelectrolytes are used instead of metallic coagulants as prime coagulant, or along with metallic coagulants as coagulant aid. As for the natural polyelectrolytes, they are quite common in the developing countries for water purification. Sanskrit writings from India reported that seeds of the nirmali tree (*Strychnos potatorum*) were used to clarity turbid river water 4000 years ago. In Peru, water has been traditionally clarified with the mucilaginous sap of "tuna" leaves obtained from certain species of cacti (Kirchmer *et al.*, 1975). This shows that the natural polyelectrolytes are widely used by villagers to remove turbidity or unpleasant taste and odor from water.

The British were among the first to use natural polyelectrolytes as coagulant aids in urban water supplies (Manual of British Water Engineering Practice, 1969). Sodium alganite, a natural polyelectrolyte extracted from brown seaweed, was used as an aid to alum, particularly during periods of low temperatures. It is widely used as thickening and stabilizing agents in the food, textile, printing and paper industries. Plants seeds that have been studied to assess their effectiveness as coagulant are *Strychnos potatorum*, *Tamerindus indica*, *Cyamopsis psoraloides*, Red Sorella, *Hibiscus sabdariffa* and *Moringa oleifera* (Schulz and Okun, 1984).

2.4 *Moringa oleifera*

Moringa oleifera which is known as horseradish (arising from the taste of a condiment prepared from the roots) or drumstick tree was originally an ornamental

tree in Sudan, planted during British rule. That was where a German scientist conducted a laboratory test to confirm the presence of a very effective coagulant in seeds of *Moringa oleifera*. *Moringaceae* is a single-genus family with 14 known species thus far, which are indigenous to Africa, Madagascar, Arabia and India (Jahn, 1981). Half of them are quite common and are sporadically cultivated. Because *Moringa oleifera* have many uses; it is planted in the whole tropical belt. In Malaysia, it can be easily found as the Indians use the pods as vegetable.

The *Moringa oleifera* is a small, fast-growing that ranges in height from 5 to 12 m, with an open, umbrella-shaped crown, straight trunk and corky (10-30 cm thick), whitish bark. The evergreen or deciduous foliage (depending on climate) has leaflets 1 to 2 cm in diameter; the flowers are white or cream coloured. The fruits (pods) are initially light green, slim and tender, eventually becoming dark green, firm and up to 120cm long, depending on the variety. Fully matured dried seeds are round or triangular shaped, the kernel being surrounded by a lightly wooded shell with three papery wings.

The plant can be easily cultivated by cutting or by seed. Seeds can be sown either directly or in containers and no seed treatment is required. The plant rise from 1 m cutting beat pods from the second year and grow onwards with maximum production in 4 to 5 years. It has also been found to well adapt to hot, humid, wet conditions with annual rainfall in excess 3000mm. However, it does best where temperature ranges from 34 to 40°C and annual total rainfall at least 500 mm (Schwarz, 2000).

Moringa oleifera is a multipurpose tree for semi-arid and drought-prone areas. It is being referred to as "miracle tree" (Fuglie, 1999). Even though it is a non nitrogen fixing tree, its different parts can be useful for other purposes. The pods, leaves, and seeds can be eaten as vegetable and highly nutritious. The extracted oil from the seeds is used for cooking, soap making, cosmetics, fuels and lamps. The wood pulp may be used for paper making. The wood is light and cannot be used for heavy constructions but it provides a fairly good fuel for cooking. The leaves can be also used as fertilizer and the very last usage is that the powdered seeds are used to

heal bacteria skin infection (all parts of the plant are used in variety of traditional medicines) (Schwarz, 2000).

2.4.1 *Moringa oleifera* Seed as Coagulant

As an alternative to conventional coagulants, *Moringa oleifera* can be used as a coagulant in household water treatment as well as in community water treatment systems, in two principal crude forms: shelled or non-shelled dry seeds (***Table 2.2***). The action of *Moringa oleifera* as a coagulant lies in the presence of water soluble cationic proteins in the seeds. These proteins are densely charged cationic dimmers with a molecular weight of about 13 kDa (Ndabigengesere *et al.*, 1995). The seedpods are allowed to dry naturally on the tree prior to harvesting. (Folkard *et al.*, 1993). When the crushed seeds are added to raw water, the proteins produce positive charges, attracting the predominantly negative charges particles, such as clay, silk, bacteria, and other toxic particles in water. Flocculation occurs when the proteins bind the negatively charged particles, forming flocs through the aggregation of particles. These flocs are easy to remove by settling or filtration.

Table 2.2: Coagulation activity of different *Moringa* forms

Forms of *Moringa*	Coagulation activity
Green pods:	
—Whole pods	absent
—Seeds	absent
—Bark of green pods	absent
—Dried green pods	absent
Dried pods:	
—Whole pods	absent
—Non-shelled seeds	
—Unfiltered	present
—Filtered	present
—Residual solids	absent
—Shelled seeds	
—Unfiltered	present
—Filtered	present
—Residual solids	absent
Bark of pods	absent
Bark of seeds	absent

(Source: Ndabigengesere *et al.*, 1995)

The seed can clarify not only highly turbid water but also water of medium and low turbidity. Ndabigengesere (1995) found that non-shelled *Moringa* seeds was almost as good as the shelled *Moringa* seeds as coagulant (***Figure 2.3***), for an initial turbidity of 426 NTU. However, when the initial turbidity was lowered to 105 NTU, shelled seeds were more effective coagulant then non-shelled ones. This means that when treating highly turbid waters, it is not necessary to separate the shell from the seed, before using *Moringa oleifera* seeds as a coagulant. Removing shells from *Moringa oleifera* seeds is a tedious process consuming time and expense.

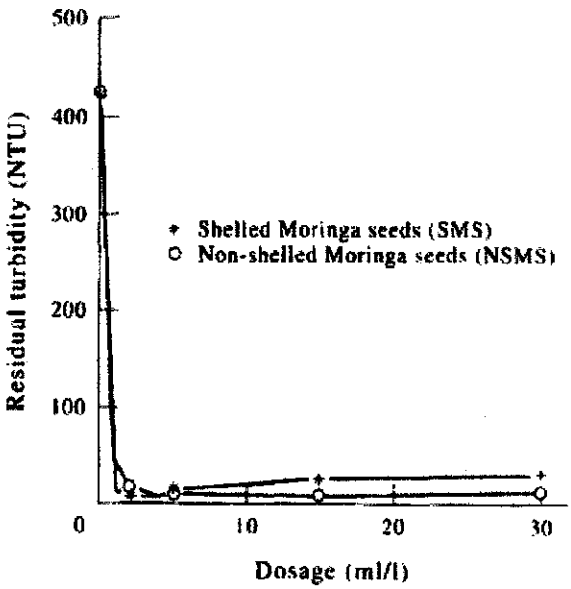


Figure 2.3: Coagulating activity of shelled and non-shelled *Moringa* seeds.

The level of turbidity influences the required time for flocculation. As with all coagulants, the effectiveness of the seeds may vary from one type of raw water to another. One advantage of seed use is that, in general, there is a wide dose range over which effective treatment may be achieved and maintained. The dose ranges shown in ***Table 2.3*** are given as a guide only, and jar testing should be carried out to determine more specific dose requirements for the raw water in question. The coagulant dosage expressed in mg/l refers to the mass of the crude powder used to prepare the *Moringa oleifera* solution, but after filtration more than 80% stayed in

solid state. This is why the coagulant dosage is also expressed in ml/l in previous related studies. *Moringa oleifera* seed dose ranged from 75 – 250 mg/l depending on the initial water turbidity (Sutherland *et al.*, 1990).

Table 2.3: Dose requirements as a function of raw water turbidity

Raw water turbidity (NTU)	**Dose range (mg/l)**
< 50	10 - 50
50 - 150	30 - 100
>150	50 - 200

(Source: Schwarz, 2000)

In optimization physical parameters studies affecting coagulation of turbid water with Moringa oleifera seeds, the removal efficiency of turbidity at optimum dosage was found to increase with increasing initial turbidity (Muyibi and Evison, 1995).

The area under cultivation to produce the annual seed requirement depends on the size of the treatment works and raw water quality (as noted in ***Table 2.3***). Assuming the average seed kernel yield for a mature tree is 3kg, then at an average seed dose of 100 mg/l the harvest from a single tree will treat 30 000 litres of water. Using the same assumptions and a recommended tree spacing of 3m, the harvest from 1 ha of mature trees (approximately 3000 kg) would treat 30 000 m^3 of water. This equates to a small treatment works producing 10m^3 per hour if operated eight hours a day for a full year. To guarantee coagulant supplies of high quality, along with speedy fruit production, big seed size, and rich yields, cultivation all over the tropical belt should be coordinated by global exchange of seed materials from the most suitable clones, special breeding efforts and subsequent local application of vegetative propagation and grafting.

In case of storage condition effects, the *Moringa oleifera* which being kept in refrigerator and room temperature for a month showed higher turbidity removal

efficiency, compared to those kept for 3 and 5 months. However, the difference between turbidity removal efficiency of *Moringa oleifera* kept in refrigerator and room temperature was insignificant. This provide positive input to explore further on preservation of *Moringa oleifera* in order to commercialize the product (S. Katayon *et al.*, 2006)

2.4.2 Comparison and use with Aluminium Sulphate

Moringa oleifera seed extracts have been proposed as substitutes for aluminium sulphate in developing countries, which based on the costs associated with alum, which may proscribe its use in poor locations. Hence studies have compared the performance of *Moringa oleifera* seed extracts with that of aluminium sulphate in terms of turbidity reductions achieved independently of the coagulant quantities consumed. For turbidities higher than 100 NTU, similar turbidity reductions were achieved with *Moringa oleifera* seed extracts and alum (Jahn and Dirar, 1979; Sutherland et al., 1990; Ndabigengesere *et al.*, 1995). Yet, at low turbidities (<50 NTU), *Moringa oleifera* seed extracts achieved at most 60% turbidity reductions (Muyibi and Okuofu, 1995). In the same study and conditions (<50 NTU), the minimum reduction achieved with alum was of 75% (40 mg/l alum dose). At low turbidities, alum is likely to perform better than non-purified aqueos extracts of *Moringa oleifera* seed extracts.

Despite similar treatment performance, *Moringa oleifera* seed extracts have some advantages over alum. The non-purified aqueous extracts are effective over a wide range of pH (Folkard and Sutherland, 2002). Unlike alum, *Moringa oleifera* derived coagulants do not affect the final pH. (Jahn, 1998; Ndabigengesere *et al.*, 1995) Sludge volumes produced using *Moringa oleifera* extracts are up to five times less than that generated with alum (Ndabigengesere *et al.*, 1995). An explanation could be that the three waters of hydration are needed to satisfy the covalent bonding of Al in commercial alum (Cornwell, 1999); this chemically bound water increases the sludge volume. It is plausible that the *Moringa oleifera* seed extract sludges

could have an advantage from a nutritional value when considering land application. Land application of alum sludge is undesirable because it may adsorb inorganic phosphorus form the soil, inhibiting phosphorus uptake from plants (Cornwell, 1999). Morover, alum sludges can also present aluminium phytotoxicity depending on its pH-dependent solubility.

Thus far, *Moringa oleifera* seed extracts have only been considered as a primary coagulant. It is contended that its use with alum could bring savings in the quantities of aluminium sulphate required for coagulation (Sutherland *et al.*, 1990). An economy of alum would demand that performance with a reduced amount used with coagulant aid is comparable to its use on its own. In this mode, Sutherland *et al.* (1990) report reduction in alum usage in the range 50-80%. Morover, for a justifiable reduction in alum usage, data fron other studies suggest alum savings 40% (Muyibi and Okuofu, 1995; Muyibi and Evison, 1996). The only hurdle to the adoption of *Moringa* for water and wastewater treatment seems to be the adequate supply of the seeds. A solution to this problem will be perhaps the intensive cultivation of *Moringa* tree in tropical countries, exactly like coffee or tea, two important cash crops grown only in tropical regions but consumed all over the world. Gene cloning can also be a possible alternative but it can be very expensive.

2.5 Analytical Methods of Colours

2.5.1 True Colour

True colour can be measured by comparator and colourimetric methods. Comparator methods rely on visual comparison of a water sample with a standard colour solution or a set of coloured filter disks. The most common comparator method involves matching a water sample with one of a series of dilutions of a standard colour solution of platinum and cobalt chloride salts of molar ratio 2:1 where the platinum concentration in mg/l is equivalent to the colour value in Hazen units (Bennett and Drikas, 1993). The Fore-Ule colour scale involves comparisons to alkaline solutions of cupric sulfate, potassium chromate and cobaltous sulfate.

The Hazen scale of true colour measurement, however, has been adopted as the reference method by organizations that set standards for water quality analysis, and by many governments in deriving their drinking water quality guidelines (APHA, 1992; NH & MRC and AWRC, 1987; WHO, 1983; EN-ISO, 1994).

Colourimetric methods are based on the calibration of absorbance of the water sample at a variety of single wavelengths, usually against the Pt-Co standard (Bennett and Drikas, 1993; Hongve and Akesson, 1996). Standard measurement comparisons can be made with sealed containers (*e.g.*, the *Hellige Aqua Tester*). Natural waters range from <5 in very clear waters to 1200 mg/l Pt in dark peaty waters (Kullberg, 1992). As some of the compounds determining the colour of water are not very stable, measurements should be made within two hours of collection (Environment Canada 1989). Comparator or visual assessment methods are not very precise.

Most operators find it difficult to distinguish between colours that differ by <5 mg/l Pt (Hongve and Akesson, 1996). Inter-laboratory comparisons of colour generally produce a standard deviation of approximately 5 to 10 mg/l Pt (Bennett and Drikas, 1993; Hongve and Akesson, 1996). Given the drinking water standard in Canada of 15 mg/l Pt (Health Canada, 1996), the coefficient of variation for maximum permitted colour is between 33 and 67%. Such uncertainty has necessitated the development of a non-visual, more precise means of quantifying true colour as calibrated against the Hazen scale. A major obstacle, however, has been to match apparatus readings with visual judgments because photometers are confined to measures at defined spectral lines or bands (Hongve and Akesson, 1996). The turbidity of natural waters also interferes with the measurement of true absorbance because spectrophotometers are not designed to measure the scattering of light (Bennett and Drikas, 1993). Therefore, several steps are required before there can be good agreement between comparator and colourimetric methods. First, turbidity must be removed by either filtration or centrifugation (APHA, 1992), or its contribution quantified (Bennett and Drikas, 1993; Hongve and Akesson, 1996). The common practice of filtration through 0.45 micron filters should be satisfactory for

most waters, although repeated filtration may be required for very turbid waters. Bennett and Drikas (1993) found that turbidity is a linear function of absorbance at selected wavelengths between 350 and 700 nm (also see ***Figure 2.4***, line P).

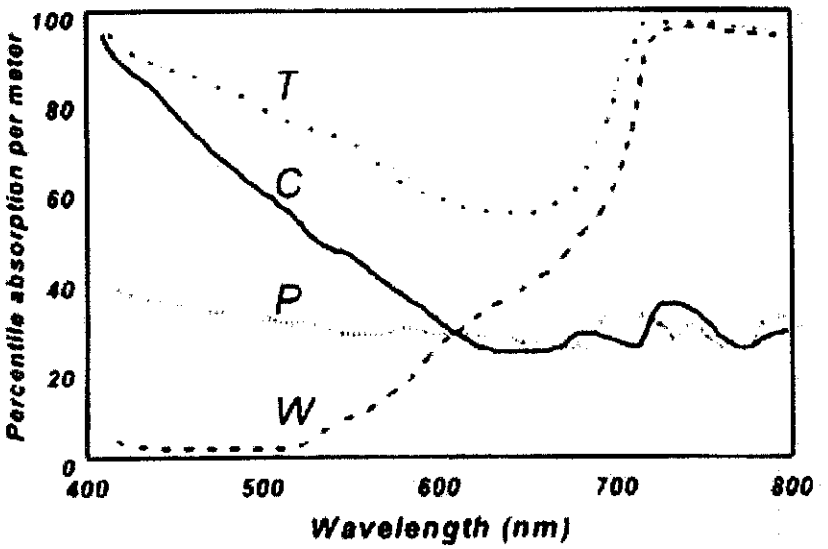


Figure 2.4:

Percentile absorption of light vs. wavelength. T is the apparent colour, C is the true colour, P is that due to suspended particulates and W is pure water. Ultraviolet and infrared wavelengths are <400 nm and >800 nm, respectively.

Using this information, they were able to derive the following equation that corrects for turbidity in photometric determinations of true colour (C) in mg/l Pt:

$$C = \frac{l}{\varepsilon \bullet \left[\left(\frac{A}{l}\right) - E \bullet t\right]} \qquad (2\text{-}4)$$

where C is the colour absorptivity (mg/l Pt/cm, E is the coefficient of scattering (NTU/cm, t is turbidity (NTU), A (in proportion) is total absorbance due to dissolved coloured species, and l corresponds to cell path length (cm). Note, however, that the correction for turbidity assumes that particle size distribution in water samples, an inherently variable characteristic in natural waters, is similar to that of the kaolin

suspension used in the calibration experiment. Although correction for turbidity would be useful in approximating true colour, it cannot be reliably applied to all waters.

Once turbidity has been removed or quantified, the next step is to select the appropriate wavelength for measuring true colour. In order to produce general agreement with comparator methods, the appropriate wavelength should exhibit equal absorbance when comparing natural coloured waters and the Pt-Co reference solution. For natural waters with high concentrations of humic and fulvic acids, this occurs around 410 nm, and 445-470 nm. The shorter wavelength has better sensitivity and one inter-laboratory comparison between Nordic countries and two inter-laboratory comparisons in Norway have shown that photometer readings at 410 nm and comparator readings gave identical results, with the former method having much better precision (Hongve and Akesson, 1996). Bennett and Drikas (1993); however, recommend single wavelength analysis at 456 nm because the influence of turbidity (after filtration) is negligible at this wavelength. Note that both comparator and colourimetric methods based on the Hazen scale are not appropriate for industrial or other wastewaters that diverge in colour from the Pt-Co standard. Coloured compounds in wastewaters and humic and fulvic acids have different absorption spectra and thus will not exhibit equal absorbance at the same wavelengths as occurs with humic and fulvic acids and Pt-Co reference solutions at 410 nm and 445-470 nm. Several of the methods discussed below are more appropriate for wastewaters.

Crowther and Evans (1981) suggested that analysis across a broad analytical wavelength range (405 to 460 nm) produces colour readings in good agreement with comparator methods. Similar good agreement has been achieved in the analytical wavelength range 445 to 470 nm by Bennett and Drikas (1993). The latter authors argue; however, that the improvement of broad wavelength analysis over single wavelength analysis is marginal with the former method requiring much additional effort.

Colour is dependent on factors that affect the solubility and stability of the dissolved and particulate fractions of the sample such as pH, temperature, exposure to light, and storage time. Although most methods recommend measurement and recording of pH, pH standardization is not desirable because the resultant colour will differ from the colour of water *in situ* (Bennett and Drikas, 1993). Also, to ensure that sample and *in situ* water colour are the same, most methods recommend that colour samples be analyzed within two hours (Environment Canada, 1989).

2.5.2 Apparent Colour

Apparent colour is due to dissolved organic matter and suspended particulates in the water such as plant debris, phyto- and zooplankton (Effler and Auer, 1987). Despite suspended particulates having relatively non-selective scattering properties, high concentrations of particulate matter of inorganic clays or volcanic ash can produce a yellow to red colour, while high concentrations of blue-green algae and diatoms produce blue-green and yellowish-brown colours, respectively (Wetzel, 1975).

Since the absorption spectrum of particulate matter is relatively non-specific, some measures of apparent colour simply estimate the reduction in light transmission or visual clarity resulting from scattering of light by particulates. The most common method for estimating visual clarity is the Secchi disk method. The Secchi disk transparency is the mean depth of the point where a weighted white disk, 20 cm in diameter, disappears when viewed from the shaded side of a vessel during mid-day, and the point where it reappears upon raising it after being lowered beyond visibility (Wetzel, 1975). The Secchi disk transparency is a function of the reflection of light from its surface and is therefore influenced by both the absorption characteristics of the water and the presence of dissolved and particulate matter. Most studies indicate, however, that particulate matter influences Secchi disk transparency to a greater extent than does true colour (Wetzel, 1975). For example, multiple regressions of

data from 55 Florida lakes yielded the following close-fitting equation (r^2 = 0.89), (Brezonik, 1978):

$$SD^{-1} = 0.106 + 0.128 \bullet T + 0.0025 \bullet C \qquad (2\text{-}5)$$

where SD is Secchi disk transparency in meters, T is turbidity in nephelometric turbidity units (NTU) and C is true colour in mg/l Pt. When only one independent variable was included in the regression equations, the r^2 value for turbidity was 0.71 and for colour it was 0.10, indicating that both variables contribute to Secchi disk transparency, although turbidity is considerably more important. In these lakes, turbidity was primarily autochthonous and thus closely related to number of algal particles.

Studies of aquatic systems in British Columbia have shown that apparent colour is often closely matched to seasonal flow patterns. Annual freshets, for example, can cause marked increases in turbidity and reductions in water clarity, particularly in glacier-fed streams (*e.g.*, Webber, 1996a, b, c; Wipperman and Webber 1996). As a result, seasonal variations in apparent colour in British Columbia aquatic systems can be dramatic. For example, apparent colour in the Salmon River at Hyder was shown to range from the detection limit of 5 TCU to a maximum of 160 TCU during the period 1982 to 1995 (Webber, 1996c).

2.6 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is a chemical procedure for determining how fast biological organisms use up oxygen in a body of water. It is used in water quality management and assessment, ecology and environmental science. BOD is not an accurate quantitative test, although it could be considered as an indication of the quality of a water source.

Most pristine rivers will have a 5-day BOD below 1 mg/l. Moderately polluted rivers may have a BOD value in the range of 2 to 8 mg/l. Municipal sewage that is efficiently treated by a three stage process would have a value of about 20 mg/l.

Untreated sewage varies, but averages around 600 mg/l in Europe and as low as 200 mg/l in the U.S., or where there is severe groundwater or surface water infiltration.

BOD measures the rate of oxygen uptake by micro-organisms in a sample of water at a temperature of 20°C and over an elapsed period of five days in the dark. There are two recognized methods for the measurement of BOD; dilution method and manometric method. However, manometric method is limited to the measurement of the oxygen consumption due only to carbonaceous oxidation, where by ammonia oxidation is inhibited. On the other hand, dilution method acquire a very small amount of micro-organism seed to be added to each sample being tested in order to ensure all other conditions are equal. This seed is typically generated by diluting activated sludge with de-ionized water.

2.7 Chemical Oxygen Demand (COD)

In environmental chemistry, the chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers), making COD a useful measure of water quality. It is expressed in milligrams per liter (mg/l), which indicates the mass of oxygen consumed per liter of solution. Older references may express the units as parts per million (ppm).

The basis for the COD test is that nearly all organic compounds can be fully oxidized to carbon dioxide with a strong oxidizing agent under acidic conditions. The amount of oxygen required to oxidize an organic compound to carbon dioxide, ammonia, and water is given by:

$$C_nH_aO_bN_c + (n + a/4 - b/2 - 3c/4)\, O_2 \rightarrow nCO_2 + (a/2 - 3c/2)\, H_2O + cNH_3 \qquad (2\text{-}6)$$

This expression does not include the oxygen demand caused by the oxidation of ammonia into nitrate. The process of ammonia being converted into nitrate is referred to as nitrification. The following is the correct equation for the oxidation of ammonia into nitrate.

$$NH_3 + 2O_2 \rightarrow NO_3^- + H_3O^+ \qquad (2\text{-}7)$$

The second equation should be applied after the first one to include oxidation due to nitrification if the oxygen demand from nitrification must be known. Dichromate does not oxidize ammonia into nitrate, so this nitrification can be safely ignored in the standard chemical oxygen demand test.

CHAPTER 3

METHODOLOGY AND PROJECT WORK

3.1 General

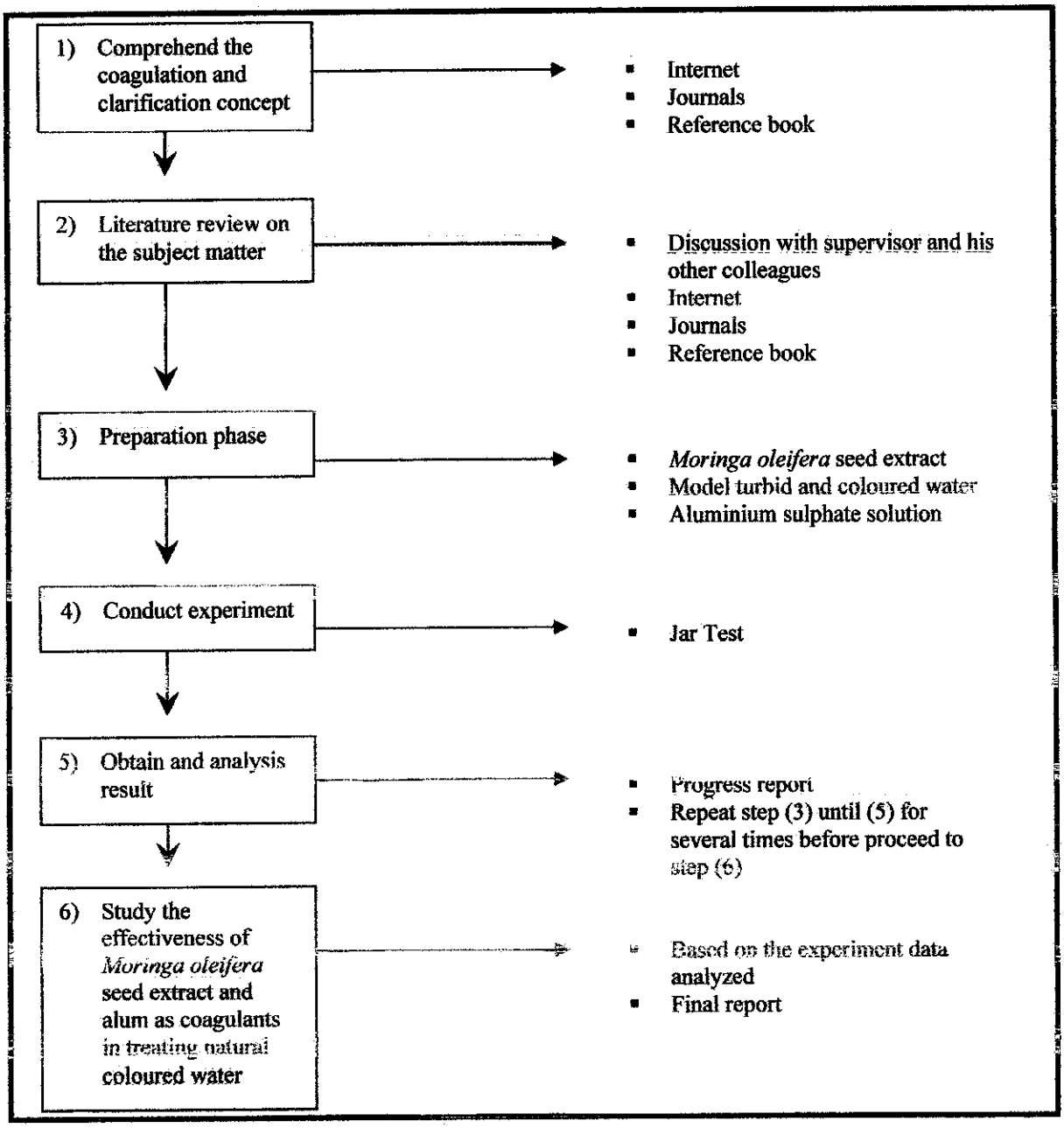


Figure 3.1: Project Flow Diagram

Figure 3.1 shows the project flow diagram which represents the complete process flow of the project. The current progress has reached phase (6), which involved:

i. Preparation phase and hazard analysis
ii. Conduct preliminary experiments
iii. Analyze all data and result obtained
iv. Conclusions and recommendations based on analysis

3.2 Experimental Design

For the laboratory tests, there were several jar tests performed with turbidity levels of 50 NTU and medium-level of true colour conditions (ca. 50 CU) with corresponding apparent colours. The model turbid water (ca. 50 NTU and 50 CU) underwent three different tests which are; by using alum as primary coagulant, *Moringa oleifera* seed extract as primary coagulant and coagulant aid to assess the effectiveness of *Moringa oleifera* seed extract in water treatment.

3.3 Preparation Phase

In this phase, several preparations were done before running the following phases. Through literature review, the basic idea about this project is known and this contributed to a successful preliminary laboratory works.

3.3.1 Natural Coloured Water

In this study, natural coloured water was used to increase the colour (i.e. true colour and apparent colour) of model turbid water. Leaves of various sizes and colours are collected and soaked in a clean plastic bottle filled with distilled water. After two (2) days, the suspension was put in a clean beaker and is stored in the cold room.

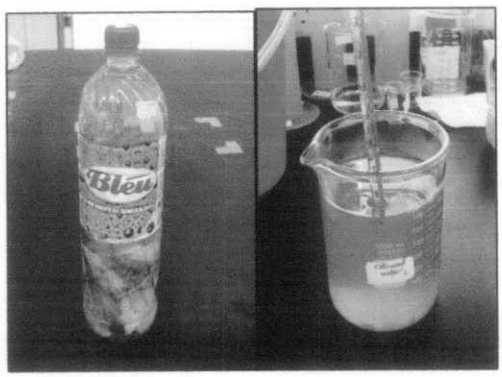


Figure 3.2: Preparation of natural coloured water

3.3.2 Model Turbid Water

The water samples used in the laboratory work were taken from nearby river, Sg. Perak (Perak River). Samples were taken on random basis and lab work was carried out after two to three days of the sample collection For longer keeping, the water samples are stored in the cold room (with temperature below 4°C), in the UTP Environmental Engineering Laboratory. The turbidity of the river water varied between 20 NTU to 80 NTU. Sample pH, apparent colour, true colour and turbidity were recorded each time the samples were collected.

As the water samples attained lower than required turbidity, a model turbid water was prepared by adding local red clay to the water samples. Approximately 100 g of red clay were added to a litre of river water. The suspension was stirred for 30 minutes and then allowed to settle for 24 hours. The supernatant was carefully removed and stored in a plastic container. The clay suspension was diluted using the same river water samples to obtain desired turbidity (c.a. 50 NTU). If the turbidity was too high, the sample was diluted with low turbidity of the same river water to obtain the required turbidity. Natural coloured water will also be added to the river water sample with purpose to increase the colour concentration according to the experimental design (ca. 50 CU).

3.3.3 Aluminium Sulphate Solution

Aluminium sulphate - hexadecahydrate ($Al_2(SO_4)_3 \cdot 16H_2O$) was used as primary coagulant at the beginning of the test in order to determine the optimum dosage for comparison with *Moringa oleifera* seed extract in the future jar tests. Solution with the concentration of 0.5% was prepared and stored in a reagent bottle. Five gram of alum were weighed and transferred into 1000 ml volumetric flask. Distilled water was added for about ½ of the volume of volumetric flask and well shaken to dissolve the alum. Additional distilled water was added exactly up to the mark of 1000 ml. For each use, alum solution is stirred for at least 1 hour.

3.3.4 *Moringa oleifera* Seed Extract

Dry *Moringa oleifera* seeds (***Figure 3.3***) were used as alternative coagulant. To prepare the solution of the *Moringa oleifera* seed extract, the husk enveloping each seed was first removed manually, good quality seeds were then selected and the kernel (***Figure 3.4***) was ground to a fine powder using mortar and pestle (***Figure 3.5***). The powder was weighed (***Figure 3.6***) and was added to the appropriate volume of distilled water. A concentration of 2% (2 g of powder in 100 ml) was used. The whole mixture was stirred for 30 minutes at room temperature (21±1 °C) using a magnetic stirrer (***Figure 3.7***). The suspension was filtered through Whatman No. 40 filter paper (***Figure 3.8***), and the resultant filtrate was then used as coagulant. In order to prevent any aging effects, such as change in pH, viscosity and coagulation activity due to microbial decomposition of organic compounds during storage, the solution was stored in the cold room at temperature below 4°C. ***Figure 3.9*** below demonstrates the stage of coagulant solution preparation.

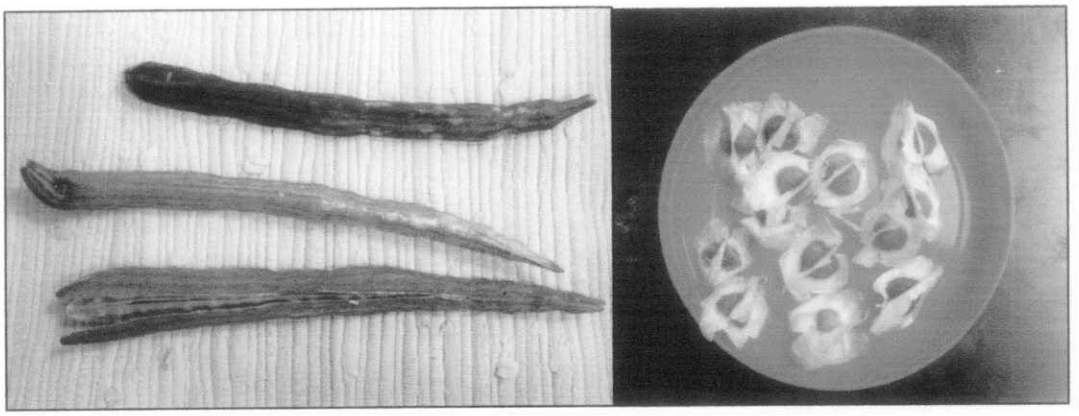


Figure 3.3: Dry *Moringa oleifera* seeds and pods

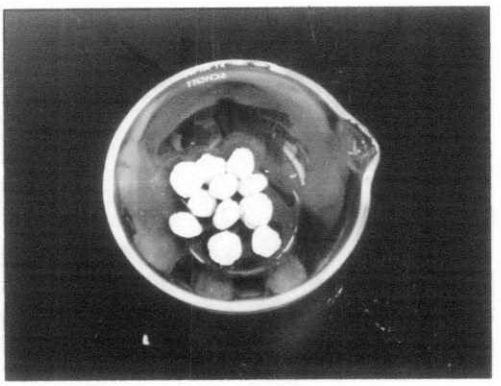


Figure 3.4: *Moringa oleifera* kernels

Figure 3.5: Mortar and pestle

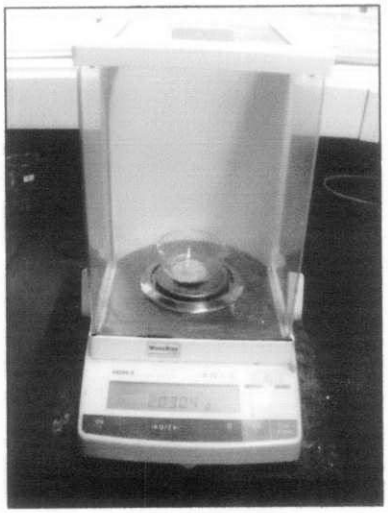


Figure 3.6: Mettler Toledo model AB204-5 weighing machine

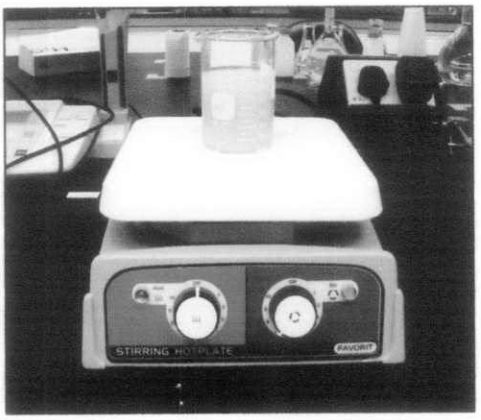


Figure 3.7: Favorit hotplate stirrer

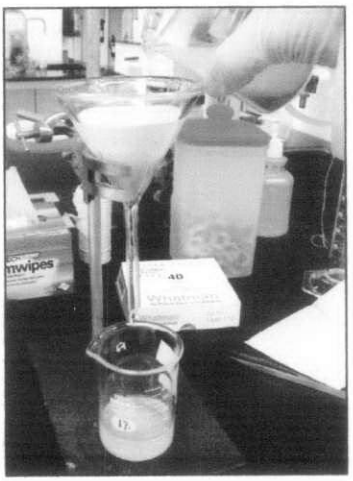


Figure 3.8: Gravity filtration using Whatman No. 40 filter paper

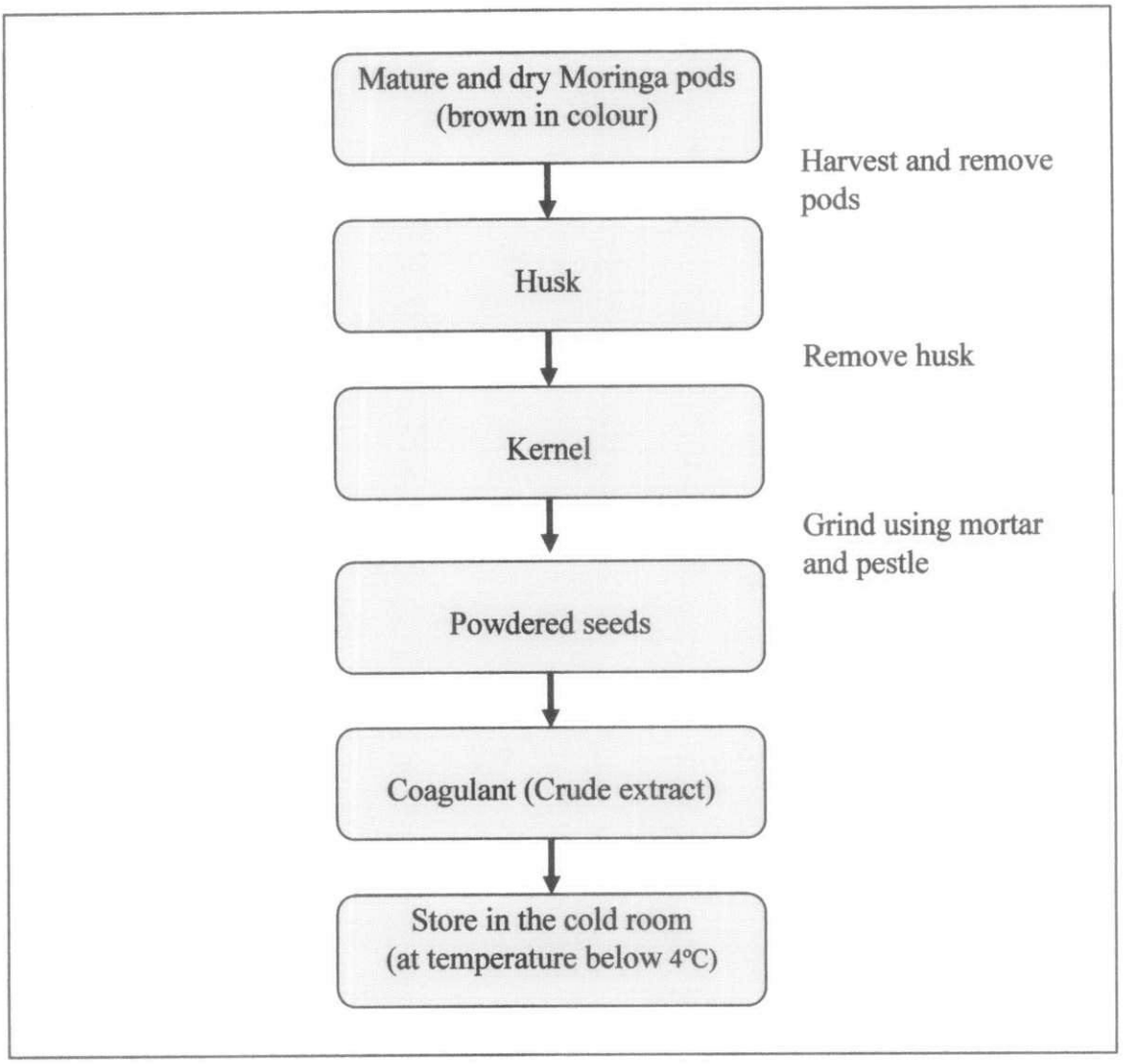


Figure 3.9: Extraction of coagulant component from *Moringa oleifera* seed

3.4 Hazard Analysis

The project conducted must comply with the UTP Laboratory General Rules and Regulations with conjunction to Health, Safety, and Environment (HSE) policies (refer to ***Figure 3.10*** in ***Appendices***). The objectives are to prevent accident, to avoid any harm to students and people surrounding, to prevent properties damage and loss event, and to take care of university image and performance.

As far as the project is concerned, it is an experimental research type that dealing with various chemical solutions and equipments, and mostly conducted in the

Environmental Engineering Laboratory. Hazard analysis must be prepared to ensure the necessary action has been taken care before, during, and after the related experiment is done.

Hazard analysis is the process of study and analyzes anything that can cause harm (e.g. electricity, chemical, etc). The conclusion of hazard identification should result in a list of hazard sources, the particular form in which that hazard occurs, the areas of workplace or work process where it occurs and the persons exposed to that hazard. Thus, from the analysis, the precaution action will be taken to reduce the probability of harm that may be dangerous to the respective people involved in the project. The hazard analysis related to the project has been tabulated in ***Table 3.1*** below:

Table 3.1: Hazard Analysis

Types of Hazard	**Applications/Job Sequence**	**Potential Hazards/Accidents**	**Recommended Safe Job Procedure**
Chemical	Aluminium sulphate	• Splashing • Spill material on to body • Inhalation (in dust form)	• Wear Personal Protective Equipment (PPE), including dust mask, goggles and protective rubber gloves • prevent eye and skin contact • conduct experiment in fume cupboard • irrigate and water flush immediately if contact; ➢ Eyes → Flush with water for at least 15 minutes ➢ Skin → Flush vigorously with water ➢ Ingestion → If victim is conscious, dilute by

			drinking large quantity of water; get prompt medical attention
Physical	Floc Tester	• Finger stuck while placing and removing the sample • Short circuit	• Keep away hands from the equipment while operating • Wear protective gloves
Physical	River water sampling	• Fall into the river	• Use automatic sampler to collect the sample
Physical	Harvesting *Moringa oleifera* pods	• Working from ladders	• Use a stable ladders • Ask an assistant to hold the ladder • Wear a proper attire (i.e. long sleeve shirt and pants)
Biological	Preparing coloured water	• Strong odour • Effected by bacteria • Splashing	• Wear PPE including protective mask, gloves and goggles • Avoid eye and skin contact

3.5 Laboratory Experiments

Within four months of project progress, three (3) jar tests were performed. In the first jar test, alum was used as primary coagulant. In the second jar test, *Moringa oleifera* seed extract was used as primary coagulant. For the last jar test, alum was used as primary coagulant and *Moringa oleifera* seed extract as coagulant aid.

3.5.1 First Jar Test

The test was done on 13th March 2008. Alum was used as primary coagulant as the objective of the test is to determine the optimum dose of alum for effective coagulation-flocculation of the model turbid water sample (c.a. 50 NTU and 50 CU).

There is no standard method for conducting the jar test. Hence, the test was adapted with our needs; a rapid mix at 100 rpm for 2 minutes, followed by slow mix for 20 minutes at 30 rpm. This was followed by 30 minutes of sedimentation. The alum dose for each jars are shown in ***Table 3.2***.

Table 3.2: Alum dose (using 5 g/l stock alum solution)

# Jar	ml of Stock Alum Solution	Alum Dose, mg/l
1	0	0
2	3.0	15
3	4.0	20
4	5.0	25
5	6.0	30
6	7.0	35

Right before the jar test, the sample pH, colour and turbidity were also recorded. Turbidimeter tube which contains the sample need to be well agitated before measured with Turbidimeter. The true colour of each water samples was obtained by using Whatman 0.45 m Cellulose Nitrate membrane filter paper. For all jar tests, Phipps & Bird Floc Tester (***Figure 3.11***), HACH 2100P Turbidimeter (***Figure 3.12***), HACH Spectrophotometer model DR5000 (***Figure 3.13***) and Mettler Toledo model MP230 pH meter (***Figure 3.14***) were used.

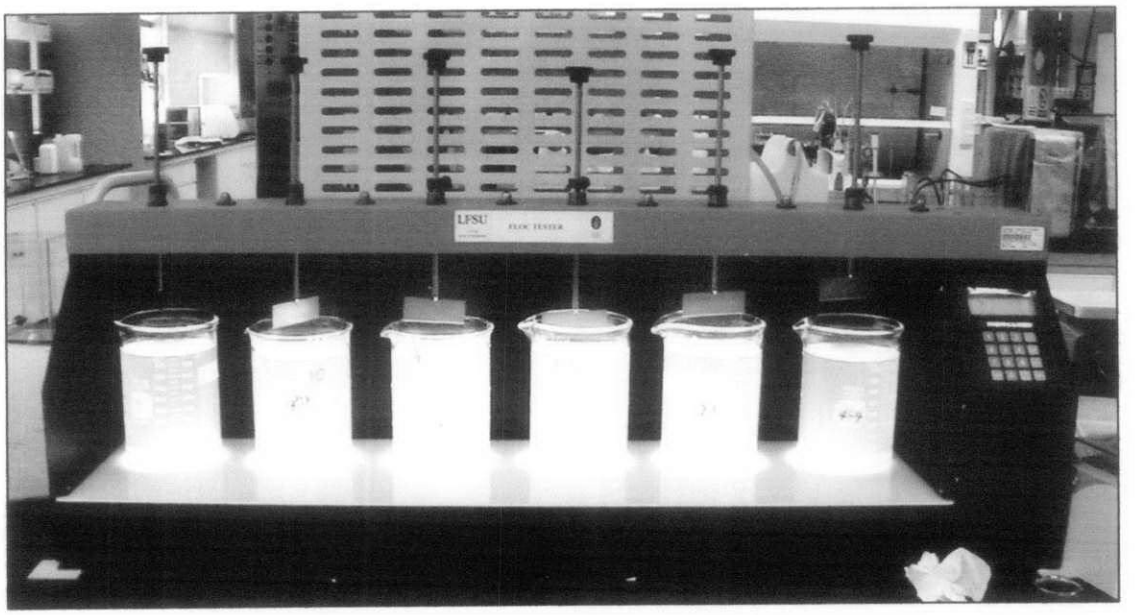


Figure 3.11: Phipps & Bird Floc Tester

Figure 3.12: HACH 2100P Turbidimeter

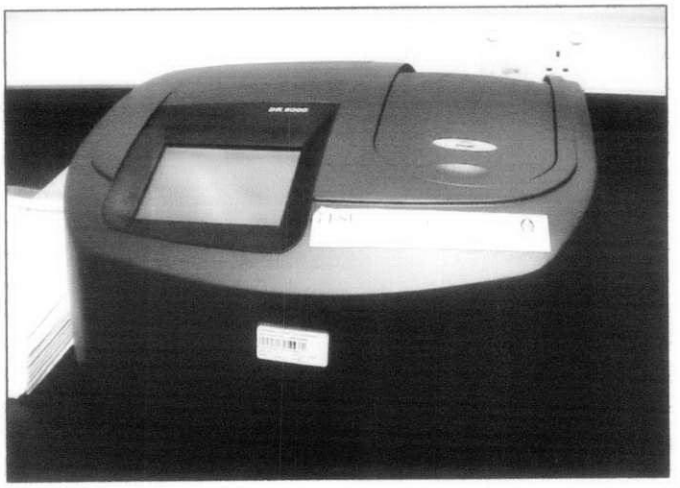


Figure 3.13: HACH Spectrophotometer model DR5000

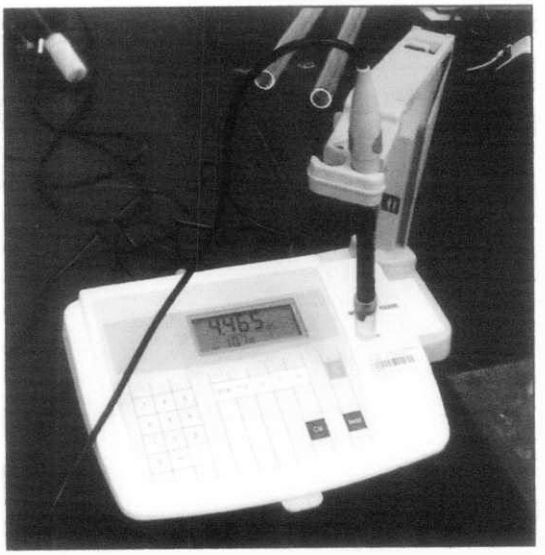


Figure 3.14: Mettler Toledo model MP230 pH meter

After 30 minutes sedimentation, supernatant of each beaker was separated into two (2) set of beakers (details are shown in ***Table 3.3***).

Table 3.3: Details of two set of samples (after jar test)

# Set	Description	Measurement (s)
A	Without filtration	• Turbidity • Apparent colour • True colour • pH
B	Filtration step by using Whatman No. 40 filter paper	

3.5.2 Second Jar Test

The test was done on 1st April 2008. *Moringa oleifera* seed extract with 2% suspension was used as primary coagulant. The objective of the test was to determine its efficiency in coagulation-flocculation process (especially in household water treatment level) and to compare with the results from first jar test.

The procedure used in this test is a repetitive of the first test. The dosage in the test was varied from 100 mg/l to 500 mg/l, as shown in ***Table 3.4***.

Table 3.4: Coagulant dose (using 20 g/l coagulant solution)

Jar #	ml of Coagulant Solution	*Moringa oleifera* seed extract, mg/l
1	0	0
2	5.0	100
3	10.0	200
4	15.0	300
5	20.0	400
6	25.0	500

3.5.3 Third Jar Test

In this section, alum was used as primary coagulant and *Moringa oleifera* seed extract as coagulant aid. The selected alum dose (ca. 15 mg/l) for this test was lesser than the optimum dosage obtained from first jar test. The purpose was to determine the efficiency of *Moringa oleifera* seed extract as coagulant aid while reducing the amount of alum as primary coagulant, and compare with the results from first and second jar test. The dosage for *Moringa oleifera* seed extract was varied from 20

mg/l to 100 mg/l, as shown in ***Table 3.5***. Results for all batch clarification tests will be compared and discussed in the next chapter.

Table 3.5: Alum (15 mg/l) as primary coagulant and *Moringa oleifera* seed extract as coagulant aid (ca. 50 NTU and 50 CU)

Jar #	ml of Coagulant Solution	*Moringa oleifera* seed extract, mg/l
1	0	0
2	1.0	20
3	2.0	40
4	3.0	50
5	4.0	60
6	5.0	70

In addition to jar test, Chemical Oxygen Demand (COD) test was performed on the model turbid water samples and the best beakers (with the lowest turbidity and colour). The purpose was to measure the level of organic matter in the treated water after adding Moringa oleifera as coagulant and coagulant aid. Method of preparing the COD samples is in accordance to the standardized procedure (as written in the laboratory manual). Figures below are some of the equipments that have been used in measuring the COD samples.

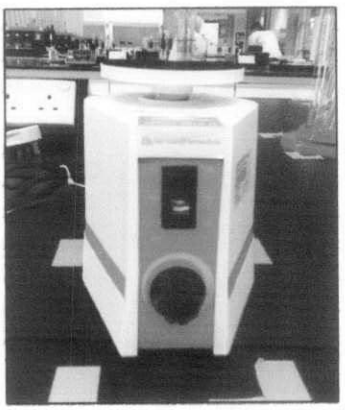


Figure 3.15: Barnstead Thermolyne Type 37600

Figure 3.16: HACH Digital Reactor DRB 200

Figure 3.17: HACH Spectrophotometer model DR 280

CHAPTER 4

RESULTS AND DISCUSSION

This chapter provides the results and discussion of the laboratory tests conducted during the observation of jar tests.

4.1 First Jar Test (ca. 50 NTU and 50 CU)

The actual turbidity and pH of the raw water taken from the river was 84.0 NTU and 6.58 respectively. After 30 minutes sedimentation, the turbidity became 78.0 NTU. The initial colour reading was recorded as 322 Apparent CU.

For this section, jar test need to be run on 50 NTU turbidity of river water. Therefore, the raw water was diluted until it reached the experimental design value. However, some of the samples might have a little bit differences in turbidity due to time of sedimentation. The range was varying at 50 ± 2 NTU; therefore it was still acceptable in this test. Meanwhile, the true colour concentration of the water was low (i.e. 28 CU). Hence, 180 ml of coloured water was added into the river water to increase its colour concentration to 50 CU (with a corresponding 355 Apparent CU). The value of pH also increased to 7.09. Although the pH reading became slightly higher than initial reading, no pH adjustment was made as the value obtained is still within the pH and alkalinity guidelines.

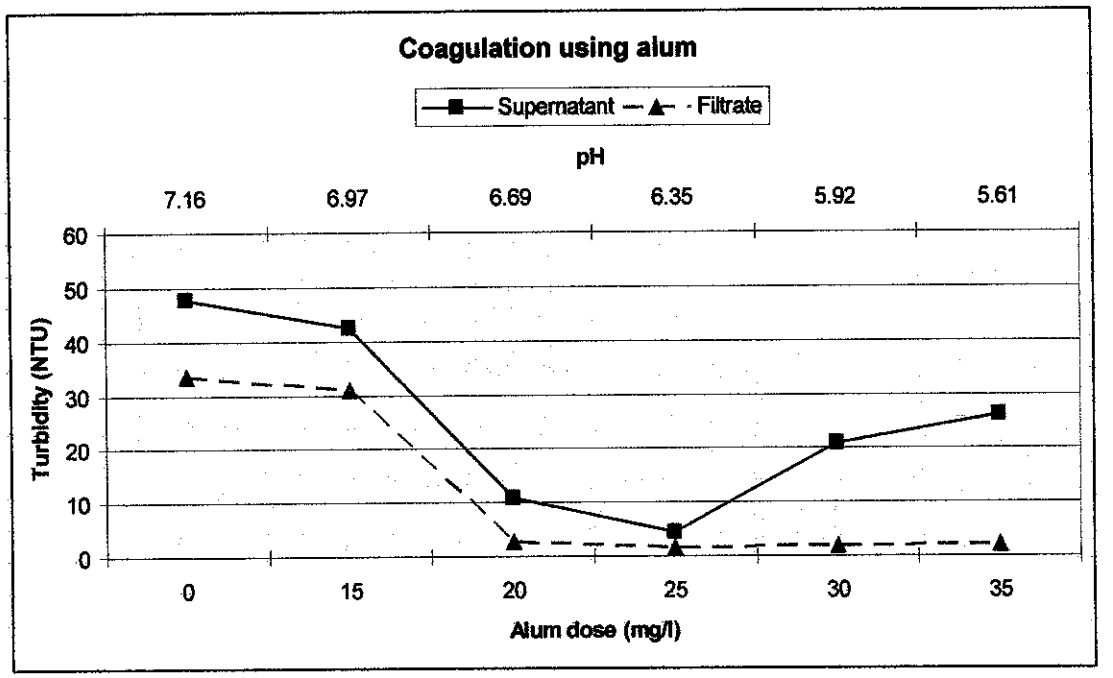
4.1.1 Determination of Optimum Dosage of Alum as Primary Coagulant

Table 4.1 below shows the supernatant turbidity, filtrate turbidity, colour and pH after test. Generally, alum showed its efficiency in removing turbidity of the water. There was a big difference in turbidity removal (more than 5 NTU) by using alum dosage from 15 mg/l to 35 mg/l. At 25 mg/l of alum dosage and pH 6.35, the

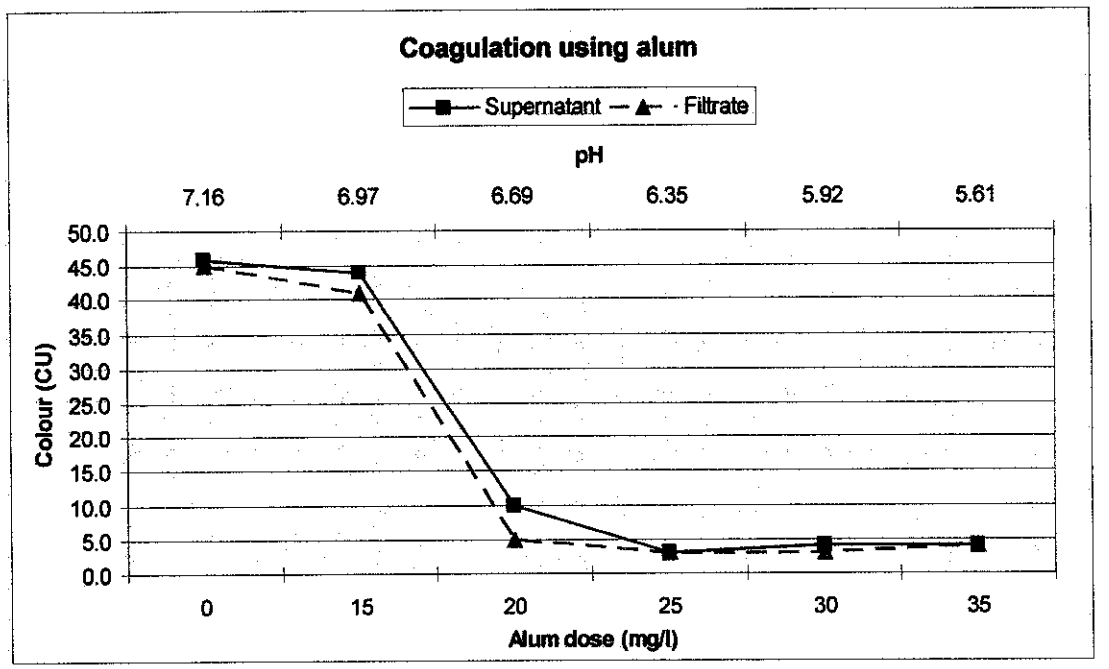
lowest turbidity of 4.52 NTU was achieved. The fourth beaker (with 25 mg/l of alum dosage) also achieved the lowest colour which was 3 CU and corresponding 23 Apparent CU. Therefore the optimum dosage for alum is 25 mg/l. The pH after test decreased gradually with the addition of alum dosage as the alum reacted with water and became aluminium hydroxide. In treating the low turbidity water, the percentage of turbidity removal for optimum dosage of alum is 96.44%. On the other hand, 92.00% of colour been removed.

Table 4.1: Alum as primary coagulant (ca. 50 NTU and 50 CU)

r	Alum Dose, mg/l	pH	Supernatant			Filtrate (after filter through Whatman No.40)			Turbidity removal (percent)	Colour removal (percent)
			Turbidity, NTU	App. Colour, App. CU	True Colour, CU	Turbidity, NTU	App. Colour, App. CU	True Colour, CU		
	0	7.16	47.70	342	46	33.60	250	45	32.80	10.00
	15	6.97	42.50	318	44	31.00	263	41	38.00	18.00
	20	6.69	10.90	64	10	2.72	18	5	94.50	90.00
	25	6.35	4.52	23	3	1.78	11	3	96.44	94.00
	30	5.92	20.80	106	4	2.07	10	3	95.86	94.00
	35	5.61	26.20	186	4	2.31	13	4	95.38	92.00



- Lowest supernatant turbidity: 4.52 NTU
- Lowest filtrate turbidity: 1.72 NTU



- Lowest supernatant colour: 3.0 CU
- Lowest filtrate colour: 3.0 CU

Figure 4.1: First jar test (ca. 50 NTU and 50 CU)

4.2 Second Jar Test (ca. 50 NTU and 50 CU)

Turbidity of the raw water was 62.7 NTU and after 30 minutes sedimentation, it became 50 NTU due to settlement of the larger particles. pH of the raw water was 6.88. After mixing the raw water sample with coloured water, the colour increased from 22 to 50 CU. This time, the value of pH decreased to 6.59.

4.2.1 Determination of Optimum Dosage of *Moringa oleifera* as Primary Coagulant

In this case, *Moringa oleifera* seed extract was used as the primary coagulant. The dosage used in the test was varied from 100 to 500 mg/l. According to Table 4.2, overall results show that *Moringa oleifera* seed extract was able to reduce turbidity and colour of the river water but not as effective as alum. The lowest turbidity and colour was achieved by 500 mg/l of the *Moringa oleifera* seed extract. Supernatant turbidity and colour were 7.26 NTU and 15.0 CU (with corresponding 78 Apparent CU). This value does fulfill the Drinking Water Quality Standards for World Health Organization (WHO) and Ministry of Health Malaysia (MOH) colour requirement which is; 15.0 CU (refer to ***Table 4.2*** in Appendices). Advantage of the seeds is that the pH after test did not change much, therefore supports the statement by Schwarz (2000).

The highest turbidity removal achieved was 91.52%. However, the percentage colour removed was only 70.00%. This proved that *Moringa oleifera* seed extract is not that suitable in treating high colour concentration in low turbidity water.

Table 4.3: *Moringa oleifera* seed extract as primary coagulant

(ca. 50 NTU and 50 CU)

Coagulant Dose, mg/l	pH	Supernatant			Filtrate (after filter through Whatman No.40)			Turbidity removal (percent)	Colour removal (percent)
		Turbidity, NTU	App. Colour, App. CU	True Colour, CU	Turbidity, NTU	App. Colour, App. CU	True Colour, CU		
0	6.52	47.60	369	48.0	33.10	318	43.0	33.80	14.00
100	6.60	49.70	388	51.0	34.70	308	50.0	30.60	0.00
200	6.56	50.90	394	53.0	38.90	337	41.0	22.20	18.00
300	6.61	19.60	181	42.0	11.50	132	37.0	77.00	26.00
400	6.59	10.20	101	34.0	6.94	98	31.0	86.12	38.00
500	5.57	7.26	78	15.0	4.24	58	15.0	91.52	70.00

4.3 Third Jar Test (ca. 50 NTU and 50 CU)

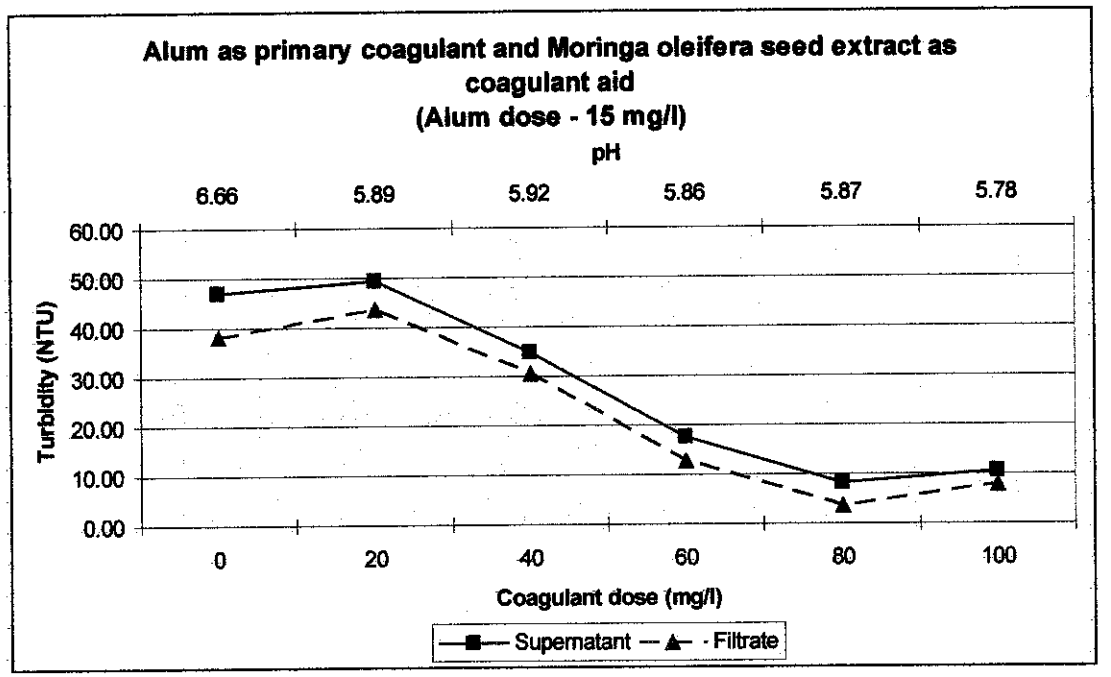
Turbidity of the water after 30 minutes sedimentation was 50 NTU and the pH was 6.98. With addition of coloured water, the pH decreased to 6.63. An amount of 15 mg/l of alum dose was added in each beaker and different dosages of Moringa oleifera seed extract (range from 20 to 100 mg/l) were added.

4.3.1 Determination of Optimum Dosage of Alum as Primary Coagulant and *Moringa oleifera* seed extract as Coagulant Aid

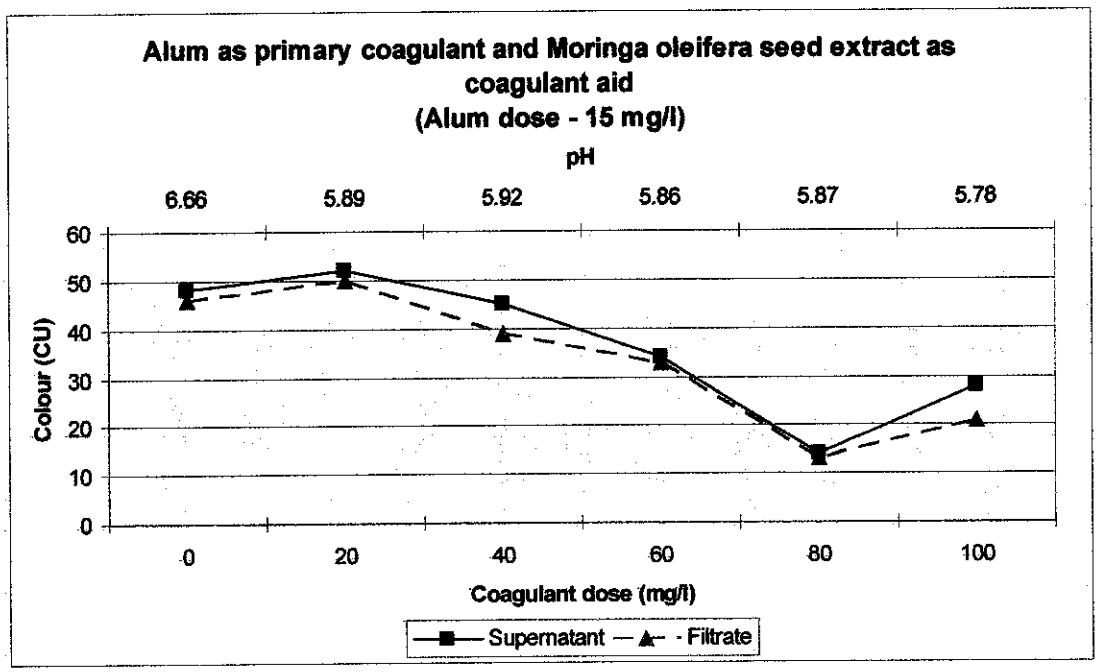
In this test, *Moringa oleifera* seed extract was used as coagulant aid. The results showed *Moringa oleifera* seed extract assisted in reducing the turbidity and colour of the model turbid water. Coagulant aid is normally added in a very small quantity (e.g. 10 to 50 mg/l), but due to high concentration of colour in the initial water, bigger quantities are proved to be more applicable. From Table 4.4, it is shown that the supernatant turbidity decreased gradually and at 80 mg/l, the best supernatant turbidity removal of the test was 8.30 NTU. The supernatant and filtrate colour also reduced to 16.0 CU and 14.0 CU respectively. Thus, in water treatment, alum could be saved by adding acceptably small amount of *Moringa oleifera* seed extract.

Table 4.4: Alum (15 mg/l) as primary coagulant and *Moringa oleifera* seed extract as coagulant aid (ca. 50 NTU and 50 CU)

Moringa oleifera seed extract, mg/l	pH	Supernatant			Filtrate (after filter through Whatman No.40)			Turbidity removal (percent)	Colour removal (percent)
		Turbidity, NTU	App. Colour, App. CU	True Colour, CU	Turbidity, NTU	App. Colour, App. CU	True Colour, CU		
0	6.66	46.90	363	48.0	38.20	335	46.0	22.60	8.00
20	5.89	49.30	381	52.0	43.50	317	50.0	13.00	0.00
40	5.92	34.70	306	45.0	30.60	262	39.0	38.80	22.00
60	5.86	17.50	178	34.0	12.60	128	33.0	74.80	34.00
80	5.87	8.30	72	14.0	3.54	61	13.0	92.92	74.00
100	5.78	10.50	96	28.0	7.92	92	21.0	86.16	52.00



- Lowest supernatant turbidity: 8.30 NTU
- Lowest filtrate turbidity: 3.54 NTU



- Lowest supernatant colour: 14.0 CU
- Lowest filtrate colour: 13.0 CU

Figure 4.3: Third jar test (ca. 50 NTU and 50 CU)

The results for COD are tabulated as below. Based on ***Table 4.5,*** the COD level has increased from 11 mg/l to 64 mg/l when the raw water is mixed with natural coloured water. This is due to the microorganism (i.e. bacteria and algae), which live inside the coloured water and act as decomposers of the organic materials. The same reason goes to the best beaker which obtained COD readings slightly higher than 100 mg/l due to *Moringa oleifera* seed extract coagulant. Hence, the treated water is not suitable for longer storage or retention time.

Table 4.5: Initial and final COD readings for the third jar test

Sample(s)	**COD readings (mg/l)**			**Average COD (mg/l)**
	1	**2**	**3**	
River water	16	17	16	16.3
Initial (River water + coloured water)	64	64	64	64.0
Final (Best beaker (the fifth jar)	106	106	105	105.7

CONCLUSIONS AND RECOMMENDATIONS

5.2 Conclusions

Based on the experiments performed, the following conclusions are made.

1. Alum as primary coagulant has produced excellent clarification by removing 96.44% of turbidity and 92.00% of the initial water.
2. *Moringa oleifera* seed extract also showed its efficiency in clarification of model turbid water, but less effective compared to alum. This is due to the higher colour concentration (ca. 50 CU) in low turbidity (ca. 50 NTU) water.
3. Analysis of the treated water shows that *Moringa oleifera* seed extract does not significantly affect the pH and alkalinity of the water, unlike alum. It also produced smaller volume of sludge.
4. *Moringa oleifera* seed extract increased the concentration of organic matter in treated water during long retention time and storage. Nevertheless, this method is likely to work in domestic household water treatment as the treated water is boiled before consumption.
5. *Moringa oleifera* seed extract showed effectiveness as coagulant aid with alum in the clarification of turbid water. Although it gives lower colour and turbidity removal compared to coagulation by just using alum as primary coagulant, a significant 40% of alum can be saved when *Moringa oleifera* seed extract is used as coagulant aid. The optimum dosage for alum and *Moringa oleifera* seed extract is 15 mg/l and 80 mg/l.
6. *Moringa oleifera* seed extract present a viable alternative coagulant to alum not only in Malaysia but worldwide as it can save the chemical cost in water treatment plants. Therefore, effort in *Moringa oleifera* plantation and processing is needed in order to reduce the cost while creating more job opportunities in the local industry.

5.2 Recommendations

The following are the recommendations, which is been proposed for future research.

1. It is advisable to start the jar test immediately after the mixed water achieved the experimental design values (i.e. 50 CU). This is to avoid colour adsorption by the colloidal particles in the water which results in less accurate colour and turbidity readings.
2. Only good quality seeds will be use in preparing the *Moringa oleifera* seed extract solution in order to maintain its coagulation mechanism in all water clarification process.
3. River systems in Malaysia vary in terms of its turbidity and colour concentration depends on the seasons (i.e. rainy or dry seasons). In order to ensure the effectiveness of *Moringa oleifera* seed extract as coagulant and coagulant aid in Malaysia's water treatment plants, further research and analysis with higher turbidity and colour concentration of model turbid water is needed. This is to avoid any plants been shutdown due to improper planning and backup strategies.

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APPENDICES

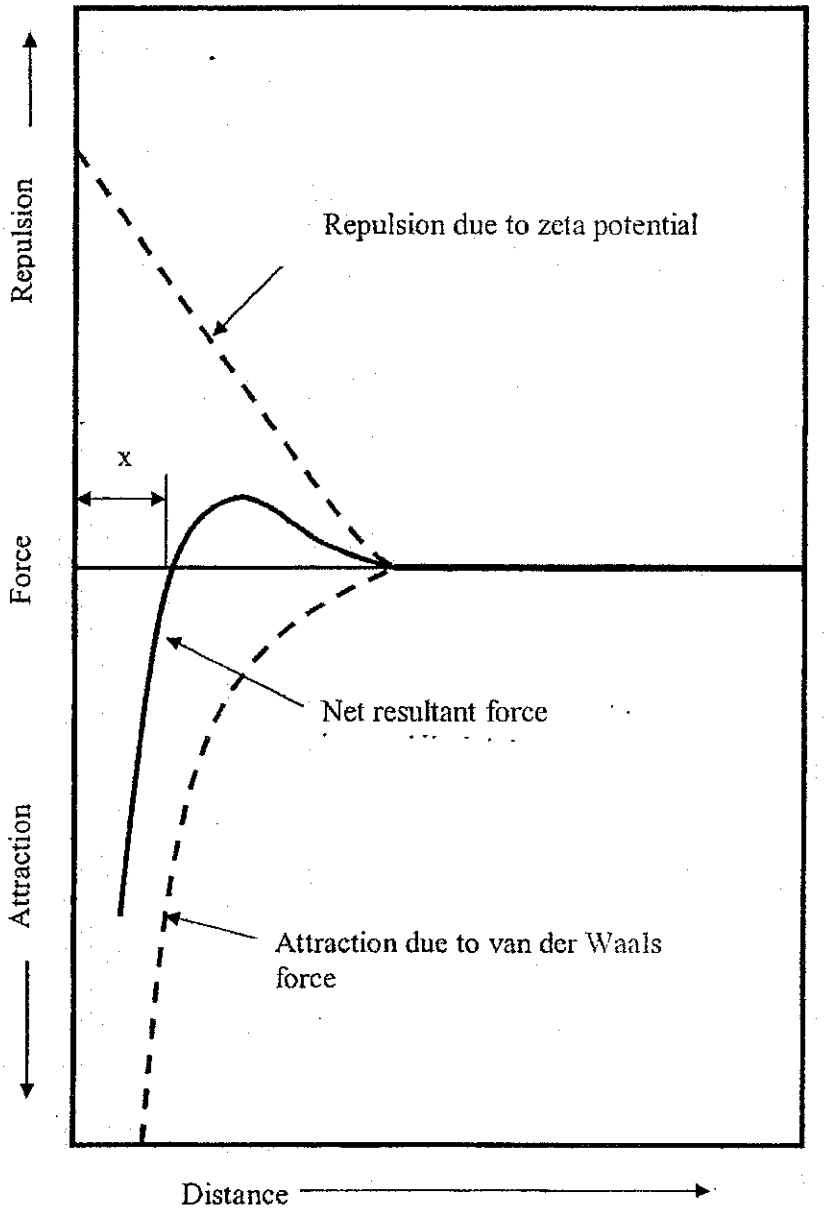

Figure 2.1: Colloidal interparticulate forces versus distance

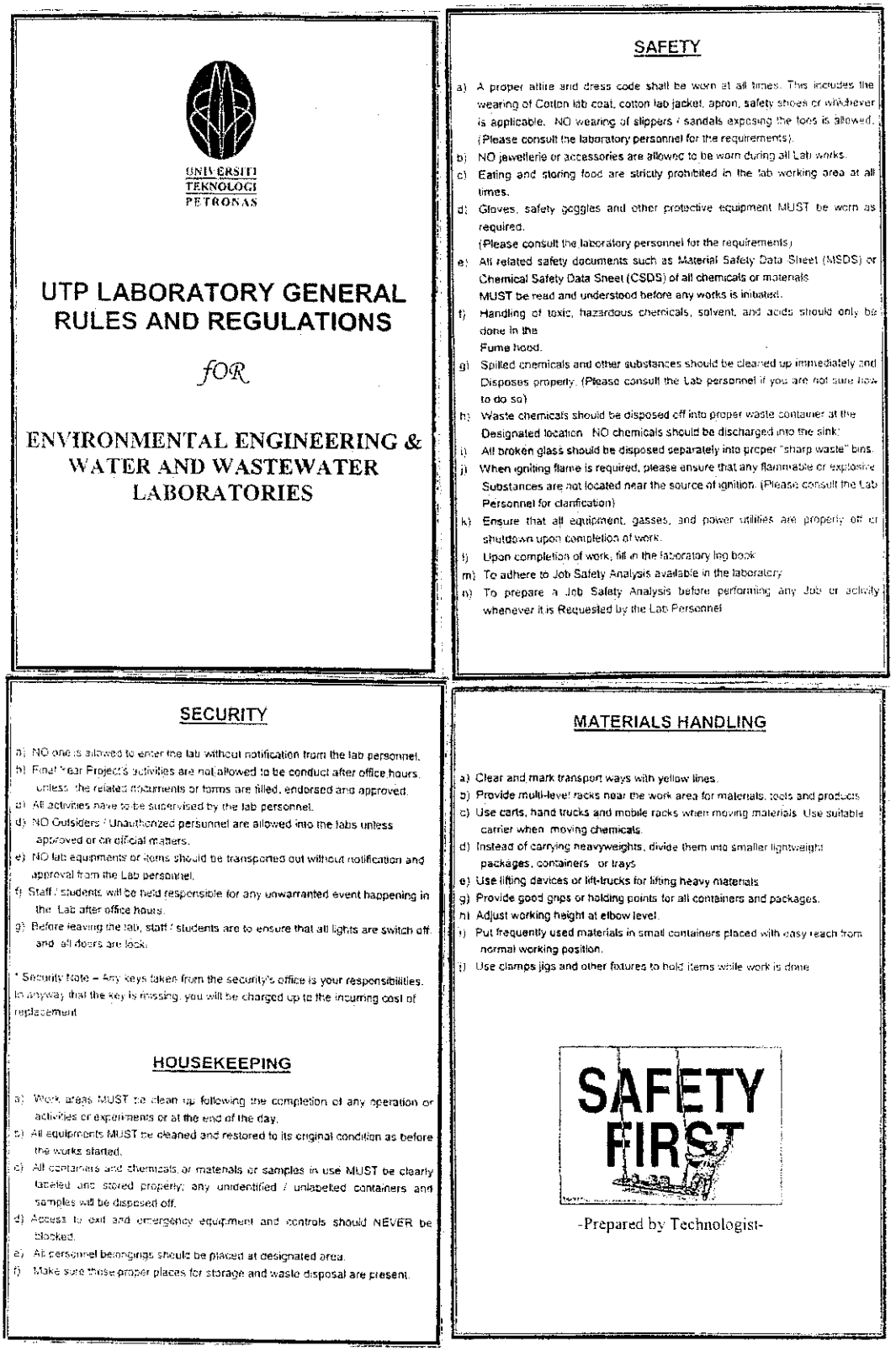

Figure 3.10: UTP Laboratory General Rules and Regulations

Table 4.2: Drinking Water Quality Standards for World Health Organization & Ministry of Health Malaysia

No.	Parameter	W.H.O. Standard*	M.O.H Standard*
1	pH	< 8.0	6.5-9.0
2	Colour (Hazen Unit)	15 TCU	15 TCU
3	Turbidity (NTU)	5 NTU	5 NTU
4	Total Alkalinity (as CaCO3), mg/l	No Spec	No Spec
5	Total Hardness (as CaCO3), mg/l	500.0	500.0
6	Calcium Hardness (as CaCO3), mg/l	200.0	No Spec
7	Magnesium Hardness (as CaCO3), mg/l	150.0	150.0
8	Total Solids, mg/l	-	No Spec
9	Dissolved Solids, mg/l	1000	1000
10	Suspended Solids, mg/l	No Spec	No Spec
11	Anionic Detergents, mg/l	1	1.0
12	Chloride (as Cl), mg/l	250.0	250.0
13	Sulphate (as SO4), mg/l	250.0	250.0
14	Selenium (as Se), mg/l	0.01	0.01
15	Mercury (as Hg), mg/l	0.001	0.001
16	Cyanide (as CN), mg/l	0.07	0.07
17	Phenol, mg/l	0.002	0.002
18	Arsenic (as As), mg/l	0.01	0.01
19	Silica (as SiO2)	-	No Spec
20	Total Iron (as Fe), mg/l	0.3	0.3
21	Copper (as Cu), mg/l	2	1.0
22	Manganese (as Mn), mg/l	0.1	0.1
23	Lead (as Pb), mg/l	0.01	0.01
24	Zinc (as Zn), mg/l	3.0	3.0
25	Cadmium (as Cd), mg/l	0.003	0.003
26	Calcium (as Ca). mg/l	200	No Spec

27	Magnesium (as Mg), mg/l	150.0	150.0
28	Nitrate Nitrogen (as N), mg/l	10.0	10.0
29	Ammoniacal Nitrogen (as N), mg/l	-	No Spec
30	Albuminoid Nitrogen (as N), mg/l	-	No Spec
31	Oil & Grease, mg/l 0.3	-	No Spec
32	Fluoride (as F)	1.5	0.5-0.7
33	Aluminium (AI), mg/l	0.2	0.2
34	Silver (as Ag)	No Spec	0.05
35	Chromium (as Cr)	0.05	0.05
36	Sodium (as Na)	200	200.0
37	Mineral Oil	0.3	-
38	Free Chlorine (as CI2)	-	Not Less Than 0.2
39	Coliform Count, org/ml	Must Not Be Detectable In Any 100ml Sample	Must Not Be Detected In Any 100ml Sample
40	E.coli Count, org/ml	Must Not Be Detectable In Any 100ml Sample	Absent In 100ml Sample